Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol 2, No.10, 2012
www.iiste.org

Radiogenic Heat Production Due to Natural Radionuclides in the Sediments of Ogun River, Nigeria

Okeyode, I.C

Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

Kamiyolejoy2000@yahoo.com

Abstract

Thirty- two sediment samples were analysed for radiogenic heat production due to the three natural radionuclides from Ogun river, using NaI(Tl) Gamma-Ray Spectrometer detector to determine the elemental concentrations of the sediments. Ogun river sediments had Shown low radiogenic heat production rate. The estimated mean of the radiogenic heat production rate was 0.48 ± 0.1 µw/m^3 and it ranged from 0.28 ± 0.2µw/m^3 (Ekerin and Mile 12-Maidan) to 0.91 ± 0.2µw/m^3 (Sokori). The overall contribution to the radiogenic heat production rates of Ogun river was mostly from Thorium, with percentage contribution of 40.44%, followed by Uranium, 31.57% and then by potassium, with 27.99%.

Keywords: Radiogenic Heat Production Rate, Ogun River

1. Introduction

The abundances of naturally radioactive elements in the earth crust constitute a large heat source to the surface heat flow, which is the density of outflow of heat from the Earth interior. Since radioactive heat sources are of first-order control to geothermals of the lithosphere, their quantification is an essential goal of heat-flow analyses, especially for the continental lithosphere, which is of extreme complexity in composition compared to oceanic lithosphere (Pereira et al, 1986). Apart from the heat content of the infant earth immediately after formation, the radiogenic decay of the unstable isotopes of uranium (^{238}U; ^{235}U), thorium (^{232}Th), and potassium (^{40}K) provides the largest internal source of heat (Clauser, 2009; Buckcr et al., 2001). The radionuclides have long half-lives comparable to the age of the earth and have significant proportion of their emissions fully converted to heat within the rocks (Ali and Orazulike, 2010). That is, the energy emitted by all these decay processes, consisting of the kinetic energy of the emitted particles and the γ-radiation associated with the different decay processes, is absorbed in the rocks and finally transformed into heat.

During radioactive decay, mass is converted into energy. Except for the tiny amount associated with the antineutrino and neutrinos generated in β^- and β+ decay or electron capture, respectively, all of the energy ends up as heat. Certain peaks in the corresponding γ-spectra are characteristic for the different decay series while the continuous background spectrum is due to Compton-scattering and photoelectric absorption (Clauser, 2009). The assessment of the amount of radioactive elements was the subject of several studies during the last few decades, due to its importance in modeling the thermal evaluation of the lithosphere. The radioactive isotopes ^{232}Th, ^{40}K, and ^{238}U contribute most of the terrestrial heat flow. If we want to understand the nature of the mantle, heat generating potential and the crust of the earth, then these elements are fundamental. The energy emitted by all of these decay processes, consisting of the kinetic energy of the emitted particles and the γ-radiation associated with the different decay processes, is absorbed in the rocks and finally transformed into heat. The study of the radiogenic heat production is important in sheding light on any anomalously high thermal regime in any of region.

2. Geography of The Study Area

Ogun river and its tributries are located in the Southwestern Nigeria, Figure 1. It is one of the series of West African rivers which do not drain into the Niger system but discharges into coastal lagoons and creeks bordering the Atlantic ocean (Sydenham, 1977). The main channel of this river rises at approximately 8º51' N, 3º38'E in Oyo State of Nigeria around Ago Fulani area runs and passes through Ogun state and enters the Lagos Lagoon at a point on longitude 3º25' E and latitude 6º35' N. The river channel in the upper section cut through the basement rocks on areas where the shallow aquifer is within 5 m of land surface. Therefore, there is a direct hydraulic connection between the river system and the upper portion of the shallow aquifers. This has encouraged fast depletion of groundwater due to rapid loss through the bottom of the channel. As cessation of rainfall starts in the month of November, the river discharges starts to decrease but can only be sustained by groundwater discharge. The low flow condition in the river (by December) makes the water level in Ogun river to drop. At the lower section of Ogun river, there is continuous interaction between the aquifer and the river channel. This confirms that there is a hydrodynamic interaction of surface and groundwater in the river sections. It is evident that surface water bodies are integral parts of groundwater flow systems. Generally, it is assumed that groundwater is recharged from areas of high elevation and discharges at lower areas; this may be true primarily for regional flow systems. Complex interactions between surface water and groundwater exist as a result of the surface water bodies being associated with the entire local flow systems (Bhattacharya and Bolaji, 2010).

Ogun river has a flowing rate and density which change depending on the geomorphology of the area between its spring and the point at which it joins the Lagoon. Taking these into consideration, the river was divided into three main parts traversing the course of the river: as Upper, Middle and Lower regions. The upper course of the river is known as the upper Ogun, the middle course, middle Ogun and lower course is known as the lower Ogun. It covers part of the following states: Oyo, Ogun and Lagos State. Some of the communities and towns along the course of the river from upper Ogun through the middle and then the lower Ogun river are: Igboho, Sepeteri, Ojubo Sango, Odo Ogun-Oyo West, Lasupo, Idi –Ata, Olopade, Olokemeji, Ekerin, Opeji, Lerin, Ago Odo, Sokori, Adigbe, Mile 8 (Oba), Abata, Owere, Ogunpa Wasimi, Iro, Magbon, Ilate, Oba Oseni, Ibaragun, Orudu, Maidan, Igaun, Akute, Kara, Mile 12- Maidan, Towolo, Agbariwu and Apa Osa etc. The river flows southwards for a distance of approximately 440 km, discharging into the Lagos Lagoon through two distributries 15 km to the North –East of Lagos city. The major tributaries of Ogun river are the Oyan and the Ofiki systems (Bhattacharya & Bolaji, 2010).

2.1 The Upper Ogun River

Two seasons are distinguishable in the upper Ogun river; a wet season with mean monthly rainfall of 972 mm from April through October, while a dry season with mean monthly rainfall of 56 mm, this occured between November and March (Adebisi, 1981). The water bed comprises mainly of fine and coarse sand particles. The river is banked by either exposed rock or muddy banks. It is composed of savanna and forest trees with aquatic grasses and shrubs. Due to the seasonal changes in the rainfall of the drainage area, there has always been an alteration in the hydrological system of this river. From July through December, the water level of the river rises as a result of the rain, making the water flow unidirectionally. After the rains the water level goes back to a point and by January, the river broke up into chain of pools. From November through April, the maximum air temperature ranged from 30.8 to 35.6ºC, between April and October , the minimun temperature varied between 18.8 and 21.7ºC (Adebisi, 1981).

2.2 The Middle Ogun River

The middle Ogun river is in the moderately hot, humid tropical climatic zone of Southwestern Nigeria. There are two distinct seasons in this region, the rainy season which lasts from March/April to 0ctober/ November and the dry season which lasts for the rest of the year. The temperature is relatively high during the dry season with 30ºC as the mean. Low temperatures are experienced during the rainy season, especially between July and August when the temperatures could be as low as 24ºC. The distribution of rainfall varies from about 1000 mm and about 2000 mm. Soils in the southwestern part of the area and most of the western part are sandy and could only support savannah vegetation. The river valleys have alluvial soils. Two main types of vegetation are observed here, tropical rain forest and guinea savanna. Soils in the northern part of the area are derived from the basement complex rocks. Soils derived from sedimentary rocks in the southern part of the area also varied in the components and texture.

2.3 The Lower Ogun River

The topography of the area is generally low-lying undulating flat landform, but with some very rugged areas having scarp slopes and gorges. The area is covered with clay-sandy soil along the coastal axis in the south and clay-loamy soil at the interior part. Apart from that, the area is still covered by forest, most of the clay-loamy soil of the interior have been greatly leached and presently look more like laterite soil. The soils are well drained with the exception of those found in the wetland areas. The vegetation of the region is that of coastal swamp and marsh/mangrove forest, part of which had given way to the construction of houses, markets and other infrastructures. Places like Apa Osa, Towolo, Akute, Maidan –Mile 12, etc., are some of the towns in this region. The climate of the area is influenced by two air masses, namely: Tropical maritime and the Tropical continental air masses. The tropical maritime air mass is warm, wet and originates from the Atlantic Ocean. The tropical continental air mass is warm, dry, dusty and originates from the Sahara desert. Hence, the climate of the area is similar to that of the other coastal region of the tropical West Africa with tropical sub-equatorial climate. The temperature is high throughout the year with an annual mean of the maximum temperature as 33.27ºC, while annual mean of the minimum temperature is 20.27ºC and the annual mean temperature is 26.77ºC. This area experiences two separate seasons, namely: the wet season, which runs from April to October, with August being the little dry season period. The main dry season is from November to March. The area records an average annual rainfall of about 1830mm, with maxima in June and September. Most rainfall experienced are of conventional origin; however, various disturbances contribute to the rainfall especially between February and May. The mean daily relative humidity of the area is 81.65% (Tejuoso, 2006).

2.4 The Geology of The Study Area

The geology of the study area, Figure 2 is described as a rock sequence that starts with the Precambrian Basement (Jones and Hockey, 1964) and which consists of quartzites and biotite schist, hornblende-biotite, granite and gneisses. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the area. The sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta formation, consists of grey sand intercalated with brown to dark grey clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base. About 9 km upstream of Abeokuta town there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal plain sands in sequence towards the Lagos lagoon (Bhattacharya & Bolaji, 2010).

2.5 Social Economic Activities of The Study Area

Ogun river serves three states (Oyo, Ogun and Lagos) greatly in terms of economic and social importance. In areas of high population density the river is used for domestic purposes such as bathing, washing and drinking. Fishing is also carried out in major part of the river. Artisanal fisheries are major activities in lower Ogun river. At Isheri-Olofin, lower Ogun river receives effluents from 'Kara'Abattoir which was established in 1984**.** An average of 200 cows are slaughtered and butchered at the abattoir on daily basis (Ikenweiwe et al., 2011). Meat and milk production are done around the river banks. The effluents being discharged into the river chiefly contain the gut contents of the slaughtered and butchered cows, therefore the river acts as sink to most organic wastes from abattoirs located along its course. The source of income of most people are based on this river because sanding and escavations are done day and night. The sediments obtained from the river is used to build houses where people live. Importantly, the three states through which the river passes, are heavily industrialised cities: most especially, Lagos and Sango – Ota(ogun state) for instance, about six major industries including Vitabiotics, Nestle, Glaxos, Smith kline, Sona Breweries and Nigerian German chemicals discharge their wastes into the river (Farombi et al., 2007). The study area is an area where there is diversification of trade. There is a dam, Ikere Gorge, situated on Ogun River, about 8 km east of Iseyin around Ojubo Sango in Oyo state. There is also a basin, which lies between latitudes 6°33N and 8°58N and between longitudes 2° 40E and 4°10E with total area of about 23,700 km^2. Different water uses, including domestic, commercial, industrial and agricultural takes place within the basin (Ojekunle et al., 2011). Farming of all sorts with the use of fertilizer to facilitate good crops, most especially cassava plantation, hunting, mat making, fishing, cloth dyeing have been the chief occupations of the local people for many decades. However, commerce and industry are other major human activities within the area, which include the Planet Plastic industries in Mile 12, sawmill (plank) industries, as well as the popular food market at Mile 12 (Tejuoso, 2006). Human and industrial activities are more at the middle and toward the lower parts of the river than at the upper part.

3. Materials And Methods

Radiogenic Heat Production (RHP) In the sediment samples of ogun river

In this work, attempt had been made so as to determine the radioactivity heat produced by the naturally occuring radionuclides present in Ogun river sediments in all the different sites of the locations covered. These kind of studies on the amount and distribution of radiogenic heat production in the sediments of different locations are of paramount importance for a complete understanding of the thermal state and evolution of the lithosphere and might shed light on any anomalously high thermal regime in any of the region.

The total heat generation A of a rock (sediment) is the sum of the individual contributions A_U, A_{Th}, and A_K by uranium, thorium, and potassium:

$$A = \rho * (C_U A'_U + C_{Th} A'_{Th} + C_K A'_K) \qquad (1)$$

where ρ is sediment density, and A' and C are the heat generation per mass of element and concentration of element in question in the sedimemt. Thus, if the density of the sediment is ρ , and its concentrations in Uranium (C_U), thorium (C_{Th}), and Potassium (C_K) are known, its radiogenic heat generation rate A can be determined, using the values given by Rybach (1988):

$$A[\mu W m^{-3}] = 10^{-5} * \rho[kgm^{-3}] * (9.52 * C_U[ppm] + 2.56 * C_{Th}[ppm] + 3.48 * C_K[\%]) \qquad (2)$$

where concentrations are given in weight-ppm (i.e. 10^{-6} kg/kg), weight-ppm, and weight-% for uranium, thorium, and potassium, respectively. The density of the sediments from Ogun river was calculated. The mass of each sediment sample was 0.25kg. The plastic containers used for the package of the sediments during measurement were cylinderical in shape and so the dimension of the volume was $\pi r^2 h$, the diameter was 6.5 cm and the height was 6.0 cm, therefore to calculate the density of each of the sediment sample

$$\text{Density of sediment} = \frac{Mass}{Volume} \qquad (3)$$

$$Density = \frac{0.25}{\Pi r^2 h} \ (\text{kg/m}^3) \qquad (4)$$

Equation (4) was used to generate the value of the density for each of the sediment sample obtained. The concentrations of the sediments in ppm (parts per million) for ^{226}Ra and ^{232}Th and in (%) for ^{40}K of each of the ten sites in the thirty –two locations were used to generate the radiogenic heat producution rates following equation 2 and the range and mean values of the radiogenic heat production rate for the upper, middle and lower regions of Ogun river are presented in Tables 1, 2 and 3 respectively.

4. Results And Discussions

4.1 Discussions

From the results obtained, the upper region, (Figure 3,Table 1), the radiogenic heat production rates was estimated to range from 0.36 ± 0.1 μw/m^3 at Igboho to 0.54 ± 0.1 μw/m^3 at Lasupo, with a mean value of 0.45 ± 0.1μw/m^3. In the middle region, (Figure 4,Table 2), the estimated value ranged from 0.28 ± 0.2μw/m^3 at Ekerin to 0.91 ± 0.2μw/m^3 at Sokori, with a mean value of 0.48 ± 0.2 μw/m^3. In the lower region, (Figure 5, Table 3), Mile 12- Maidan had the least value of 0.28 ± 0.2 μw/m^3 and Ogunpa Wasimi had the highest value of 0.81± 0.3 μw/m^3, the estimated mean for the region was 0.50 ± 0.1 μw/m^3.

Considering the whole Ogun river, the total mean was estimated to be 0.48±0.1 μw/m^3, ranging from 0.28 ± 0.1μw/m^3 (Ekerin and Mile 12-Maidan) to 0.91 ± 0.2μw/m^3 (Sokori). This means that Ogun river sediments had Shown low radiogenic heat production rate less than 1 μw/m^3.

It was observed that the highest value of the radiogenic heat production rate was from the middle region of the river and the lowest values were both from the middle (Ekerin) and lower (Mile 12- Maidan) regions of the river. Although it is expected that the upper region of the river should have higher value of the RHP rates due to the nature of the geology of the area as having made up of the basement complex rock, i.e granitic rocks, although some parts of the middle region also consist of granitic rocks. This could be that the Uranium and Thorium concentrated in % granites of one generation may be strongly depleted or homogenized during the metamorphism of another. Only granites that consolidate after the thermal peak of the last metamorphism in an area are likely to have relatively high radiogenic heat production (Costain et al., 1979). Pollack and Chapman (1977) showed that RHP contributes about 45% of the surface heat flow observed over the continents, while Lachenbruch (1970), Swanberg (1972) and Lowrie (1997) showed that its magnitude exponentially decreases with depth. This decay indicates that RHP comes from a superficial layer of the crust, 4 to 16 km thick, but which averages 10 km. Measurements of RHP show that the acidic rocks have the highest rate of production followed by the basic (rocks/ sediments that are low in silica e.g basalt), and ultrabasic ones (with high iron content: describes igneous rock that is high in iron and magnesium and contains no free quartz), in that order (Rybach, 1986; Cermak et al., 1990; Brown and Musset, 1993). The amount of heat generated by the decay of the radioactive elements of interest depends on the quantities present, their rates of decay as well as the energies of the emissions. The results obtained from the present study were comparable with the results obtained by some other researchers. Pereira et al (1986), found the average RHP of Sao Paulo, Brazil continenental shelf sediments to be 0.6 ± 0.04 μwm^{-3}. Murugesan (2004) reported that the heat production rate of Cauvery river sediments in Tamilnadu, India ranged from 0.1858 ± 0.0073 μW m^{-3} to 3.0389 ± 0.0758 μW m^{-3} with the mean value of 0.5568 ± 0.0062 μW m^{-3} . Some of their values were higher than that of Ogun river but their mean values were relatively close. It was also reported by Bucker et al (2001) that the radiogenic heat production obtained from drillhole CRP-3 in the northern part of McMurdo basin Antarctica had average values between 0.5 and 1.0 μW/m^3. Distribution of heat production values having observed peaks at 0.5 and 1.0 μ/Wm^3 can be attributed to sandstones and mudstones, respectively. Diamictites and conglomerates show intermediate heat production values (Bucker et al, 2001). The distribution of heat production values of Ogun river ranged between 0.28 and 0.91 μ/Wm^3, hence this could be attributed to the range of heat production values of sandstones (Bucker et al, 2001). Also, Radiogenic heat production estimated from the concentrations of the radioactive elements obtained from log data from a well drilled in the Chad Basin, NE Nigeria ranged between 0.17 and 1.90, having an average of 0.90 ± 0.01 μW m^{-3} reported by (Ali, and Orazulike, 2010). From the work of Joshua et al (2008), it was observed that ^{232}Th was the highest contributor to the radiogenic heat production in the crustal rock samples of South-Eastern Nigeria studied, Cross-River State was the only State in which the contribution of ^{238}U was higher than that of ^{232}Th. The total contribution to the radiogenic heat production rates of Ogun river was mostly from thorium, and its percentage contribution was 40.44%, followed by uranium and its contribution was 31.57% then by potassium, with 27.99%.

Although high radioactive concentrations of a particular radionuclide at a given location does not necessarily imply high contribution to radiogenic heat production rate (Josha et al 2008). This study was able to give an insight of the percentage RHP rate that contributed to the surface heat flow due to the radionuclides considered in the work.

5. CONCLUSION

The estimated mean of the radiogenic heat production rate was 0.48 ± 0.1 μw/m^3, and it ranged from 0.28 ± 0.2μw/m^3 (Ekerin and Mile 12-Maidan) to 0.91 ± 0.2μw/m^3 (Sokori). The Ogun river sediments showed low radiogenic heat production rate. The overall contribution to the radiogenic heat production rates of Ogun river was mostly from Thorium, with percentage contribution of 40.44%, followed by Uranium, 31.57% then by potassium, with 27.99%.

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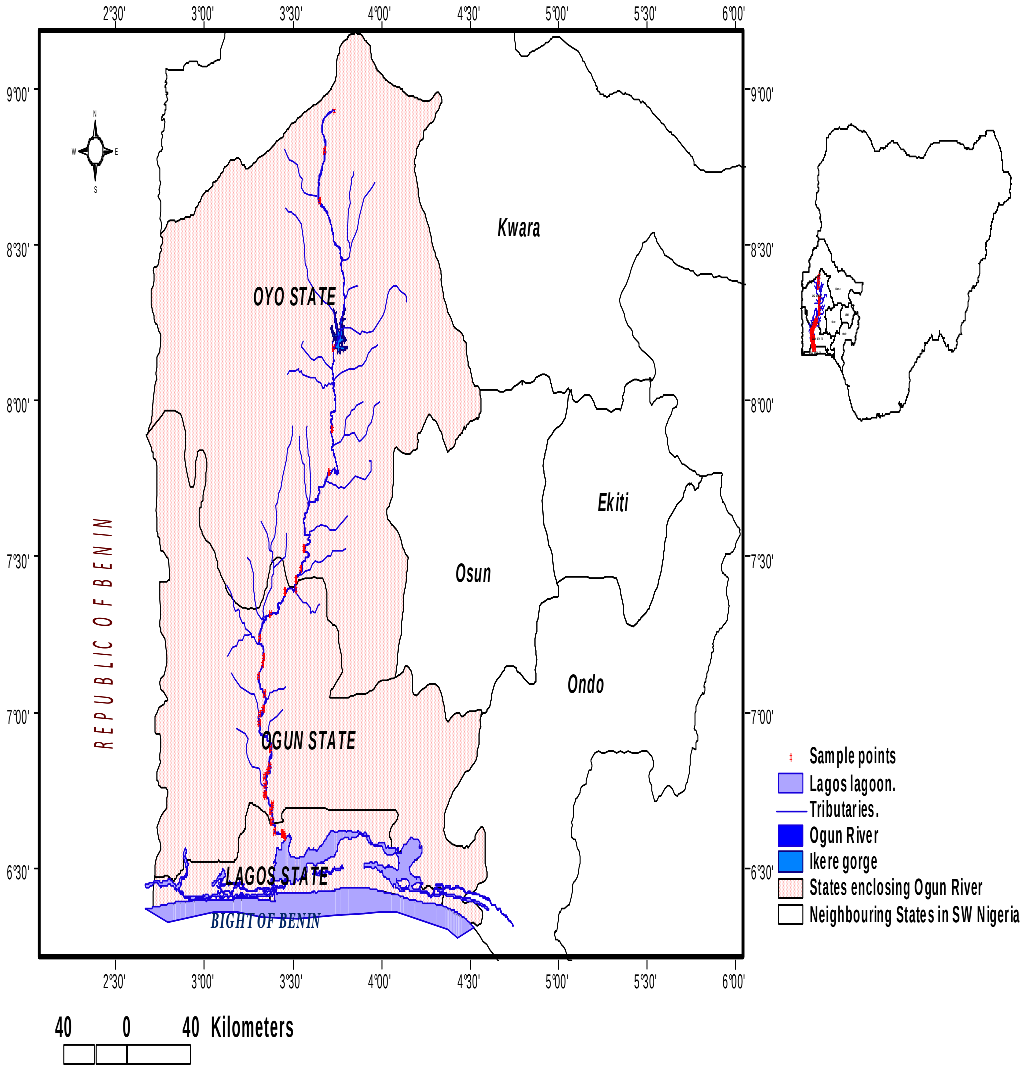

Fig. 1: Map of South Western Nigeria showing the study area and the three states the river traversed (Okeyode, 2012)

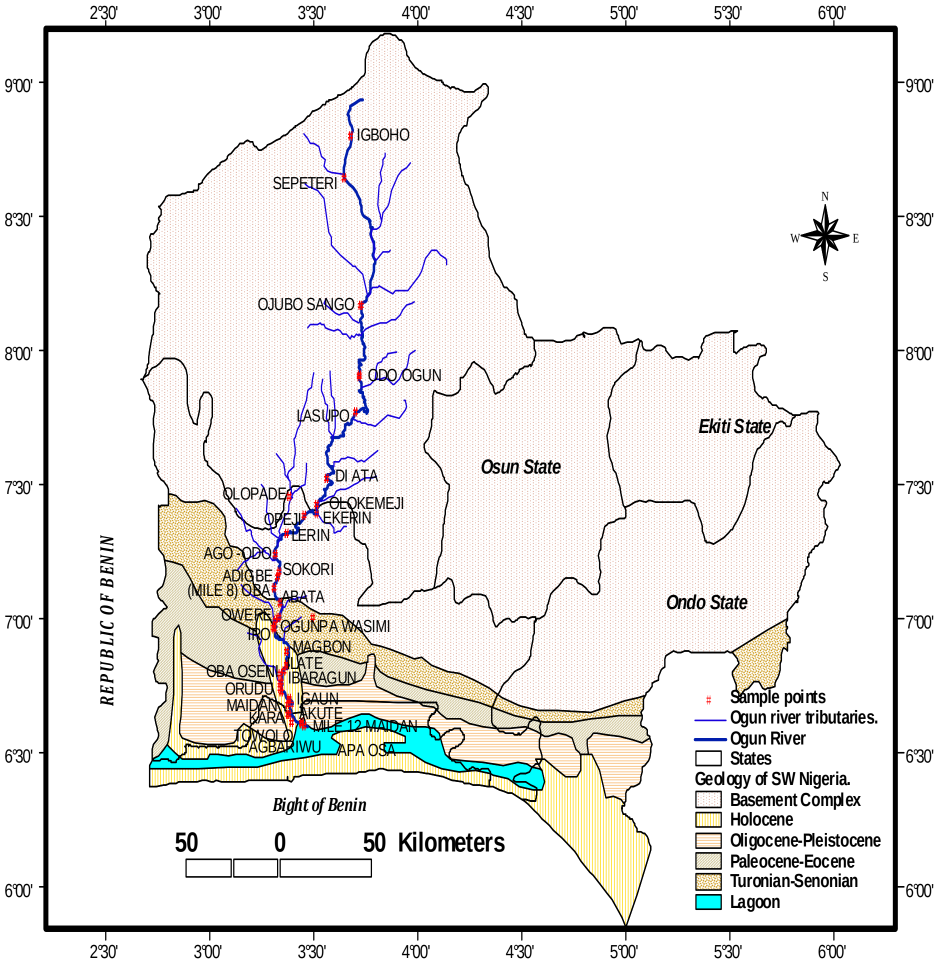

Fig. 2: The geological map of SouthWestern Nigeria showing the distribution of major rock types and sites of study (Okeyode, 2012)

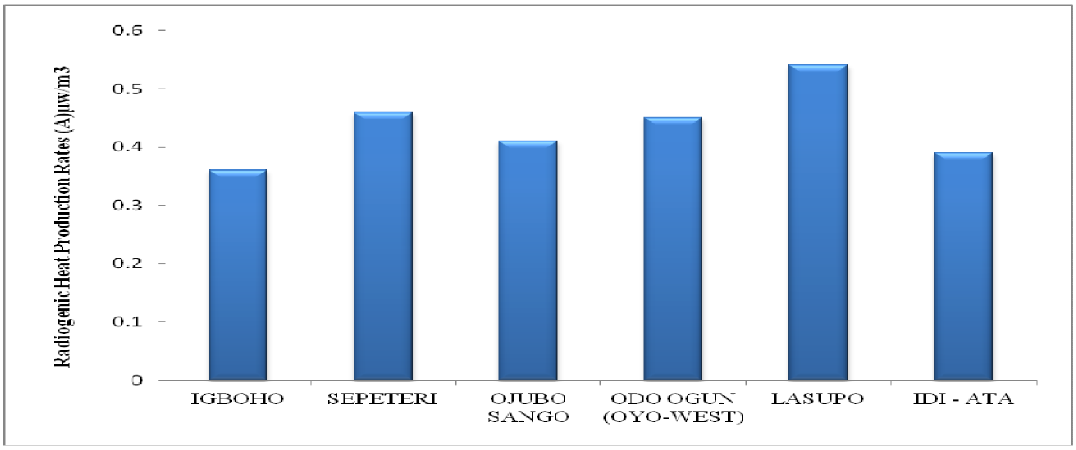

Fig. 3: Distributions of the radiogenic heat production rates for upper Ogun river

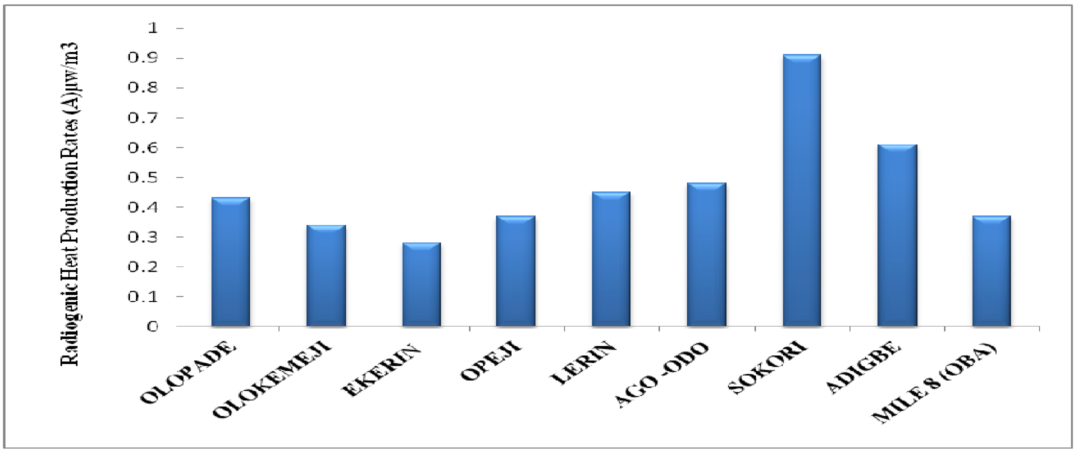

Fig. 4: Distributions of the radiogenic heat production rates for middle Ogun river

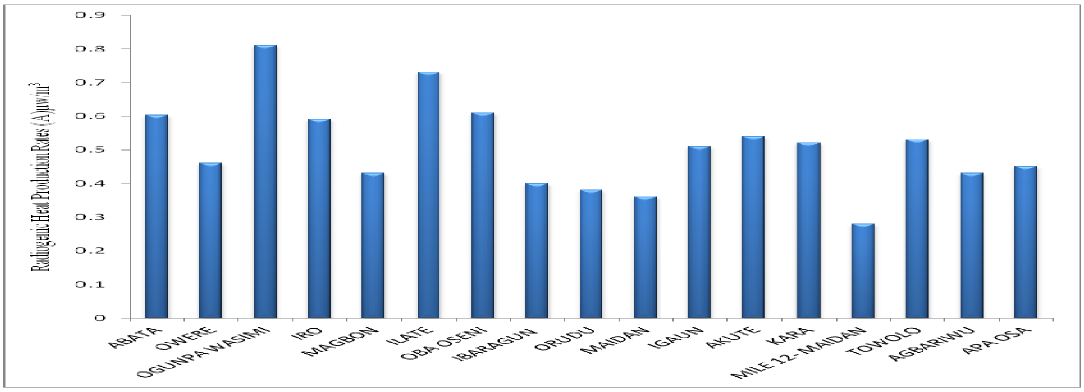

Fig. 5: Distributions of the radiogenic heat production rates for lowerr Ogun river

4.1 Results

Table 1: Range and mean of the radiogenic heat production rates in the upper region of Ogun river sediments

S/N	LOCATION	Ck(%)	Cu (ppm)	CTh(ppm)	(A)µw/m^3
1	IGBOHO	1.9250	0.8418	2.1181	0.36 ± 0.1
2	SEPETERI	1.8690	0.9579	2.2292	0.46 ± 0.2
3	OJUBO SANGO	1.6880	0.8665	2.3583	0.41 ± 0.1
4	ODO OGUN (OYO-WEST)	1.7040	1.1370	2.412	0.45 ± 0.1
5	LASUPO	1.6710	1.1558	2.3532	0.54 ± 0.1
6	IDI - ATA	1.4760	0.9120	2.0449	0.39 ± 0.1
Mean					0.45 ± 0.1
Range				0.36 – 0.54	

Table 2: Range and mean of the radiogenic heat production rates in the middle region of Ogun river sediments

S/N	LOCATION	Ck(%)	Cu (ppm)	CTh(ppm)	(A)µw/m^3
1	OLOPADE	1.2275	1.2177	1.9509	0.43 ±0.2
2	OLOKEMEJI	1.5239	0.7558	1.8455	0.34 ± 0.1
3	EKERIN	1.6370	0.4555	1.9778	0.28 ± 0.2
4	OPEJI	1.4291	1.0461	1.5908	0.37 ±0.1
5	LERIN	1.8600	0.8411	2.1520	0.45 ± 0.1
6	AGO -ODO	1.7745	0.8775	2.1946	0.48 ± 0.2
7	SOKORI	1.4783	1.6687	5.6690	0.91 ± 0.2
8	ADIGBE	1.5271	1.2903	2.8787	0.61 ± 0.2
9	MILE 8 (OBA)	1.9484	0.6885	2.6784	0.37 ± 0.1
Mean					0.48 ± 0.2
Range			0.28 – 0.91		

Table 3: Range and mean of the radiogenic heat production rates in the lower region of Ogun river sediments

S/N	LOCATION	Ck(%)	Cu (ppm)	CTh(ppm)	(A)µw/m^3
1	ABATA	1.5416	1.3997	4.9261	0.60 ± 0.2
2	OWERE	2.0115	0.9186	3.0229	0.46 ± 0.1
3	OGUNPA WASIMI	1.8193	1.5071	5.1635	0.81 ± 0.3
4	IRO	1.7925	1.3507	3.6843	0.59 ± 0.3
5	MAGBON	1.6688	1.1953	2.1562	0.43 ±0.2
6	ILATE	1.6583	1.2613	4.4571	0.73 ± 0.4
7	OBA OSENI	1.6306	1.1505	5.5213	0.61 ± 0.2
8	IBARAGUN	1.6159	0.8062	2.6363	0.40 ± 0.2
9	ORUDU	1.6124	0.9079	1.9706	0.38 ±0.1
10	MAIDAN	1.6772	0.8159	1.9502	0.36 ± 0.1
11	IGAUN	1.3008	1.3906	2.6784	0.51 ±0.1
12	AKUTE	1.8454	1.3143	4.5426	0.54 ±0.2
13	KARA	1.4735	0.6827	1.3516	0.42 ± 0.1
14	MILE 12-MAIDAN	1.6379	0.6365	1.2365	0.28 ± 0.2
15	TOWOLO	1.4293	1.2519	4.1683	0.53 ± 0.2
16	AGBARIWU	1.4544	0.7393	4.2119	0.43 ± 0.1
17	APA OSA	1.9966	1.0763	2.3645	0.45 ±0.1
Mean					0.50 ± 0.1
Range			0.28 – 0.81		